Discovering a Higgs decaying to 4 jets in SUSY Cascade decays

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in collaboration with Bellazzini, Csaki and Hubisz

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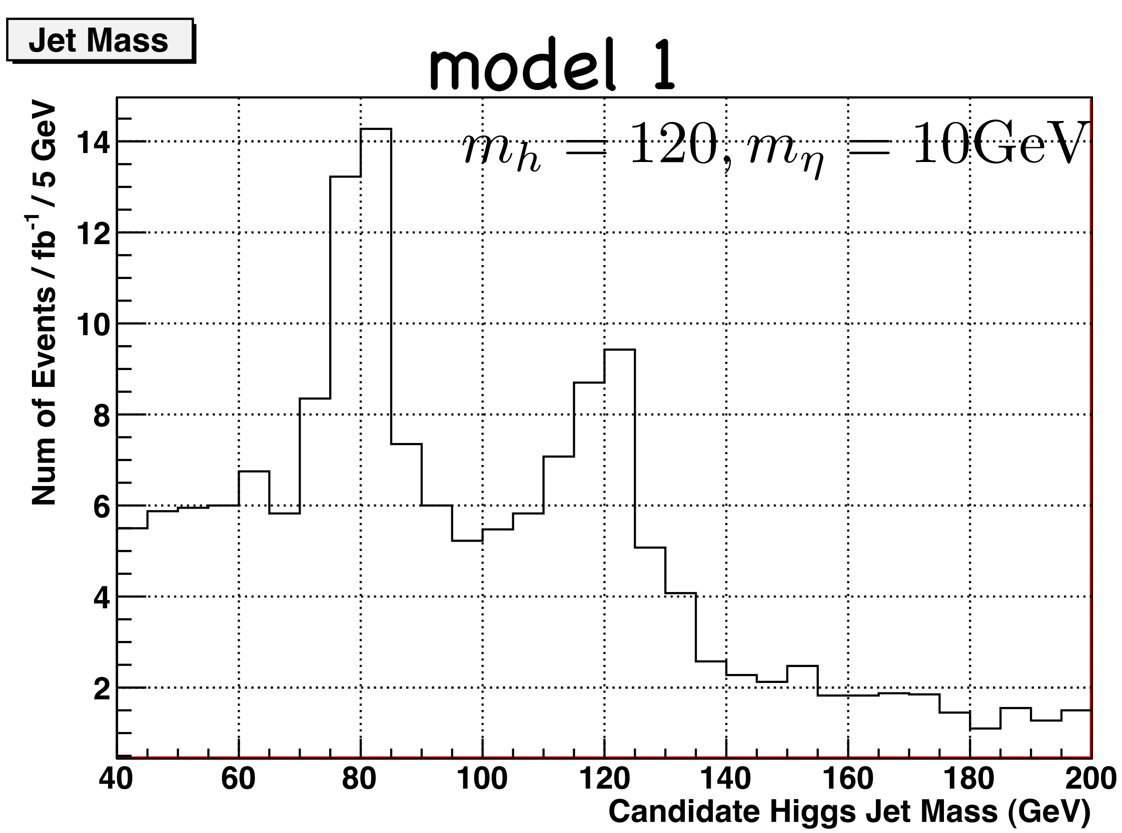
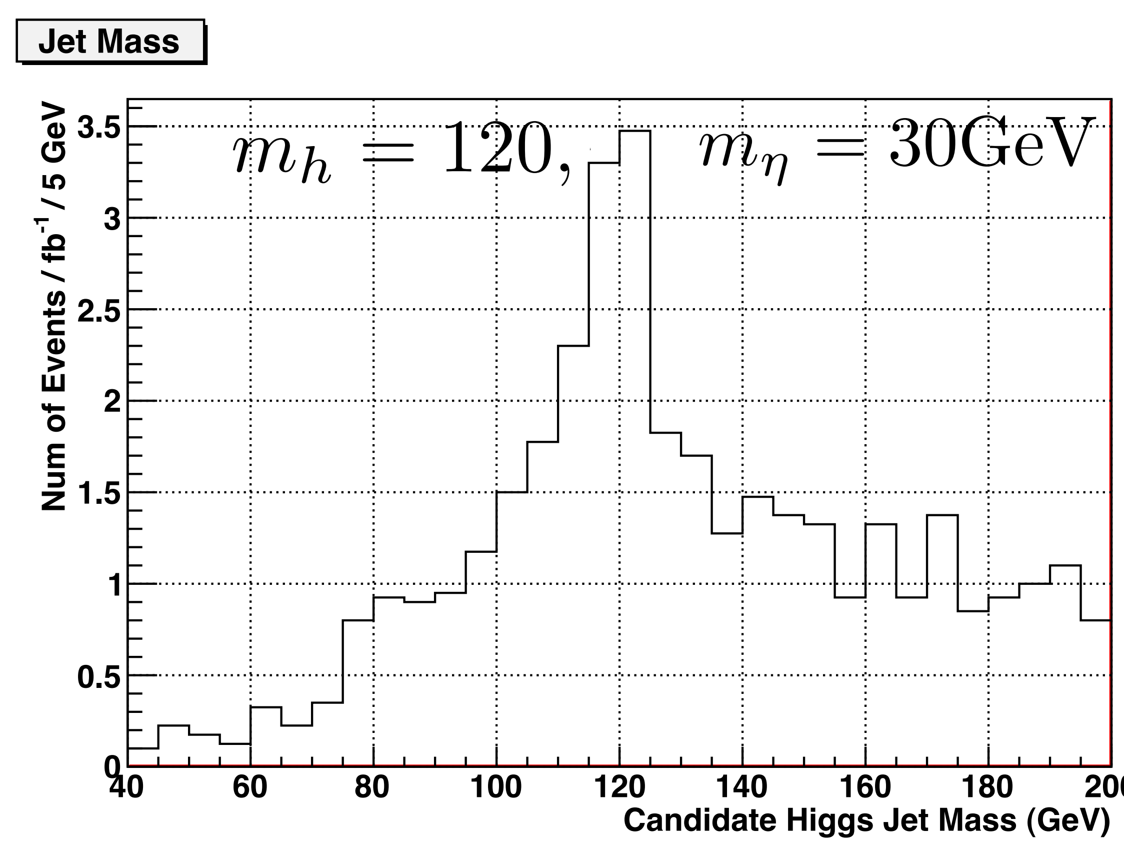
Outline

- Why is Higgs still missing?
- How to deal with Higgs decaying to jets?
- How can new physics help?
- Case study
- Conclusions

Summarize the result

- Higgs can decay 4 light jets -- suffer from large SM Bkg
- jet substructure + new physics channels can enhance the discovery
- 14TeV LHC -- 10-30fb^-1

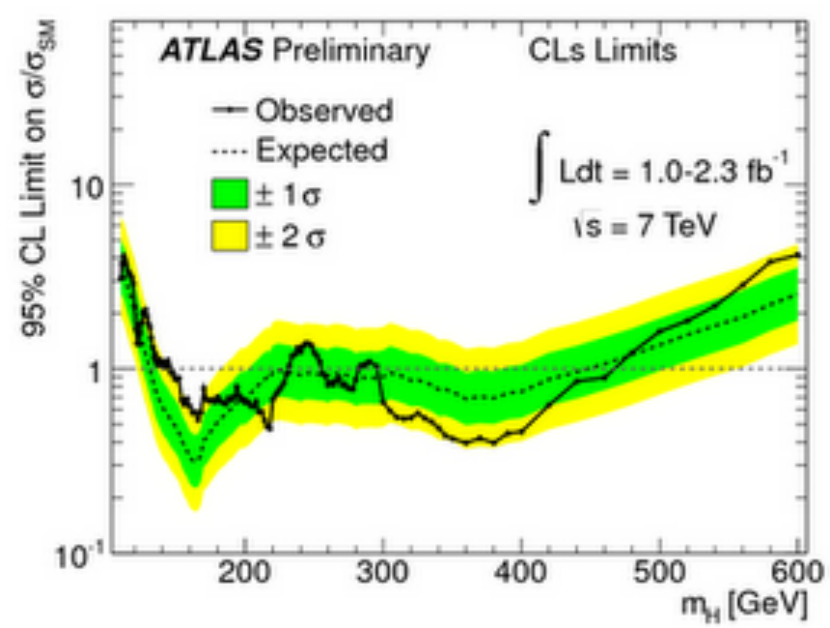




Why is Higgs still missing ?

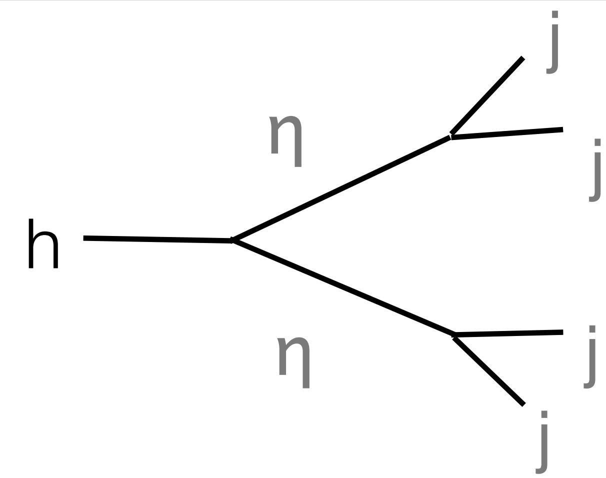
- LEP
  - m_h>115 GeV
  - h-> 4c,4g or other light jets
- Tevatron & LHC
  - no evidence yet
  - for SM Higgs, 115-145GeV

Decay Channel	**Limit**
$h \to b\bar{b}$ or $\tau\bar{\tau}$	115 GeV
$h \to jj$	113 GeV
$h \to WW^*$ or ZZ^*	110 GeV
$h \to \gamma\gamma$	117 GeV
$h \to \not{E}$	114 GeV
$h \to AA \to 4b$	110 GeV
$h \to AA \to 4\tau, 4c, 4g$	86 GeV
$h \to$ anything	82 GeV



Nonstandard Higgs decay

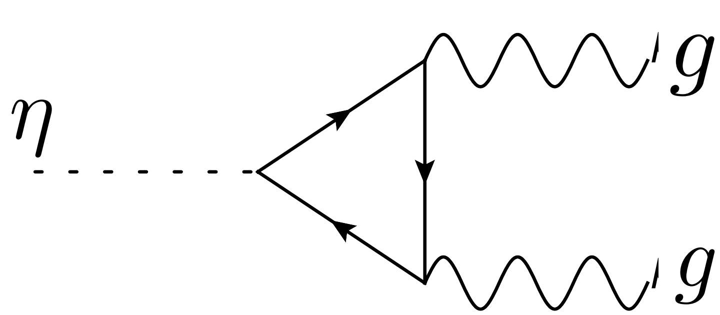
- H decay to light jets: H-> 4jets
- New scalars couple to Higgs
  - Extended Higgs sector: NMSSM, ...
  - Buried/Charming Higgs: SU(3)-> SU(2), PGB: h, η



Bellazzini,Csaki,Falkowski,Weiler(2009,2010)
Dermisek,Gunion(2005)
Luty,Phalen,Pierce(2010)
Carpenter,Kaplan,Rhee(2008)
Cripaios,Pomarol,Riva,Serra(2009)
......

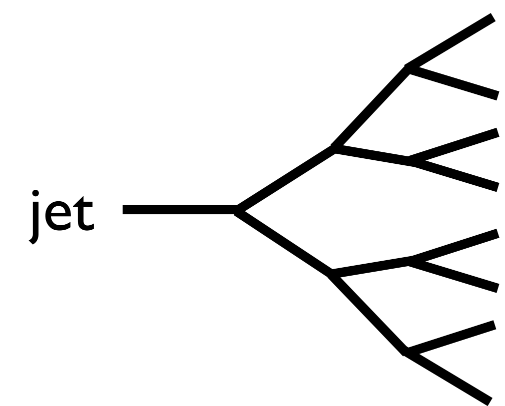
	$SU(3)_C$	$SU(3)_W$	$U(1)_X$
$\mathcal{H}_u, \Phi_u$	1	$\bar{3}$	$1/3$
$\mathcal{H}_d, \Phi_d$	1	3	$-1/3$

$$\mathcal{H}_u^T = f s_b \begin{pmatrix} \sin(\tilde{h}/\sqrt{2}f) \\ 0 \\ e^{i\tilde{\eta}/\sqrt{2}f}\cos(\tilde{h}/\sqrt{2}f) \end{pmatrix}, \quad \mathcal{H}_d = f c_b \begin{pmatrix} \sin(\tilde{h}/\sqrt{2}f) \\ 0 \\ e^{-i\tilde{\eta}/\sqrt{2}f}\cos(\tilde{h}/\sqrt{2}f) \end{pmatrix}.$$



How should we do?

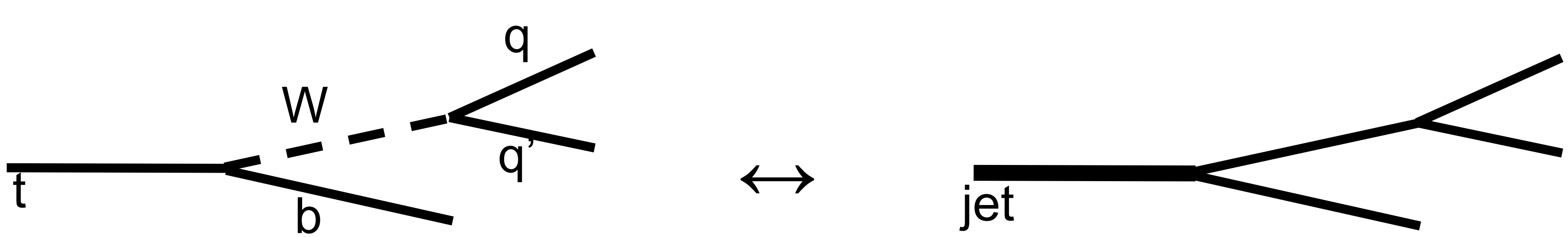
- Normally form jets and combine them --> invariant mass
- Cluster a “fat” jet, then check the cluster sequence
  - mimic the physical process of showering
  - kinematic cuts iteratively, determine whether from decay or QCD radiation
  - jet mass/kinematics/jet shape



sequential clustering:

$$d_{ij} = \min(k_{ti}^{2p}, k_{tj}^{2p}) \frac{\Delta y^2 + \Delta\phi^2}{R^2}$$

Kt(p=1),anti-Kt(p=-1),C/A(p=0)



Implementations

- Many ways developed

  BDRS, “Y-splitter”, “Top-tagging”
  Jet grooming : Pruning, Trimming
  Jet shapes

  Brooijmans(2008), Kaplan etal (2008),Thaler,Wang(2008), Ellis,Vermilion,Walsh(2009), Krohn,Thaler,Wang(2009), Almeida etal (2008), Kim(2010),Thaler & VanTilberg (2010) ......

- Butterworth, Davison, Rubin and Salam (BDRS) 0802.2470
  Search SM Higgs to bb

  - mass drop: m(subjet)< m(jet); decay kinematics: Kt dist > y m(jet)

  - Filtering: recluster with smaller R, keep hardest 3 subjets

- Modified procedure Higgs -> 4g , need 100fb^-1 @14TeV LHC

  Chen,Nojiri,Sreethawong(2010)
  Falkowski,Krohn,Shelton,Thalapillil,Wang(2010)

Reduction of Bkg with new physics signals

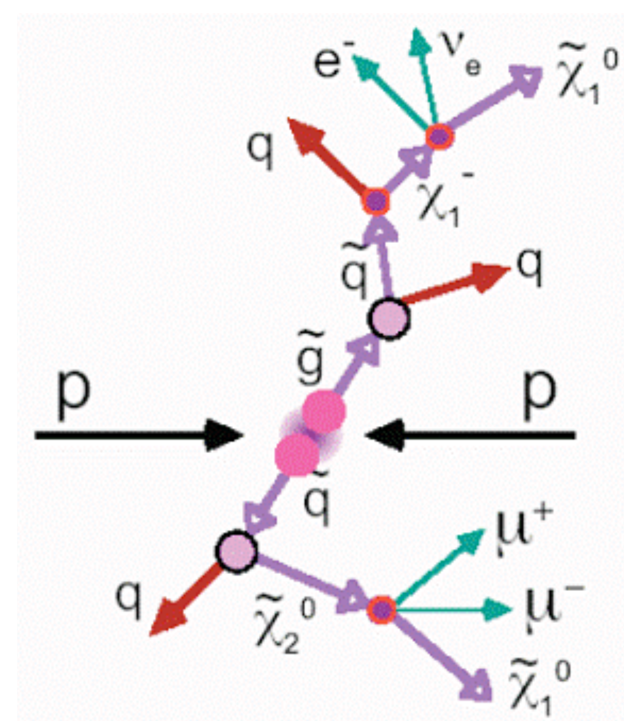
- Nonstandard Higgs decay implies new physics

- New colored exotics (> TeV) pair produced, e.g. gluino-gluino, squark-gluino, etal

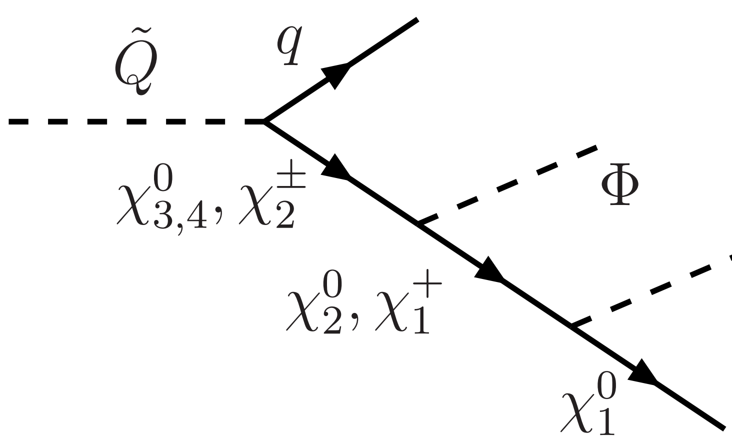
- Cascade decay

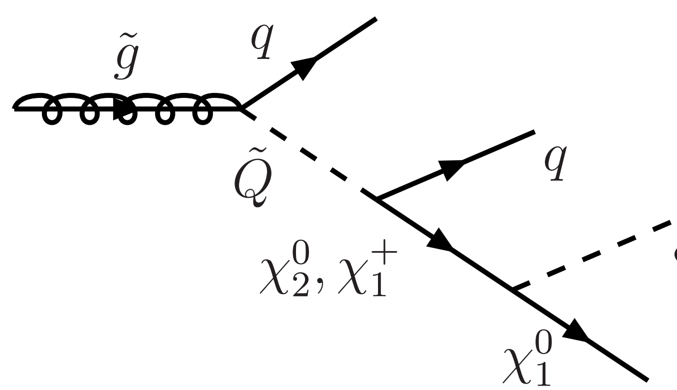
⟹ multi-jets + Large MET + H_T

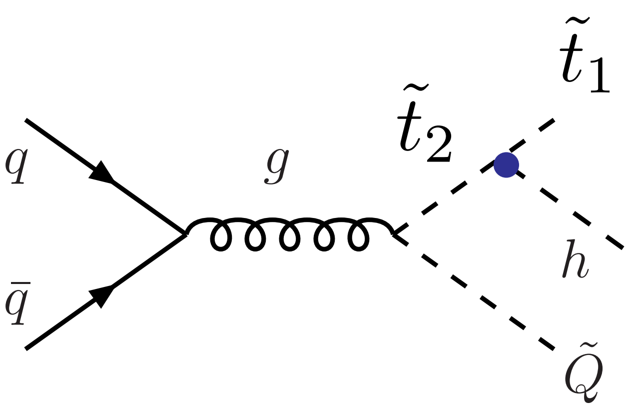
(assume lightest exotic is stable or long-lived)



Higgs from SUSY Cascade







gaugino-higssino-higgs coupling

higgs-squark-squark

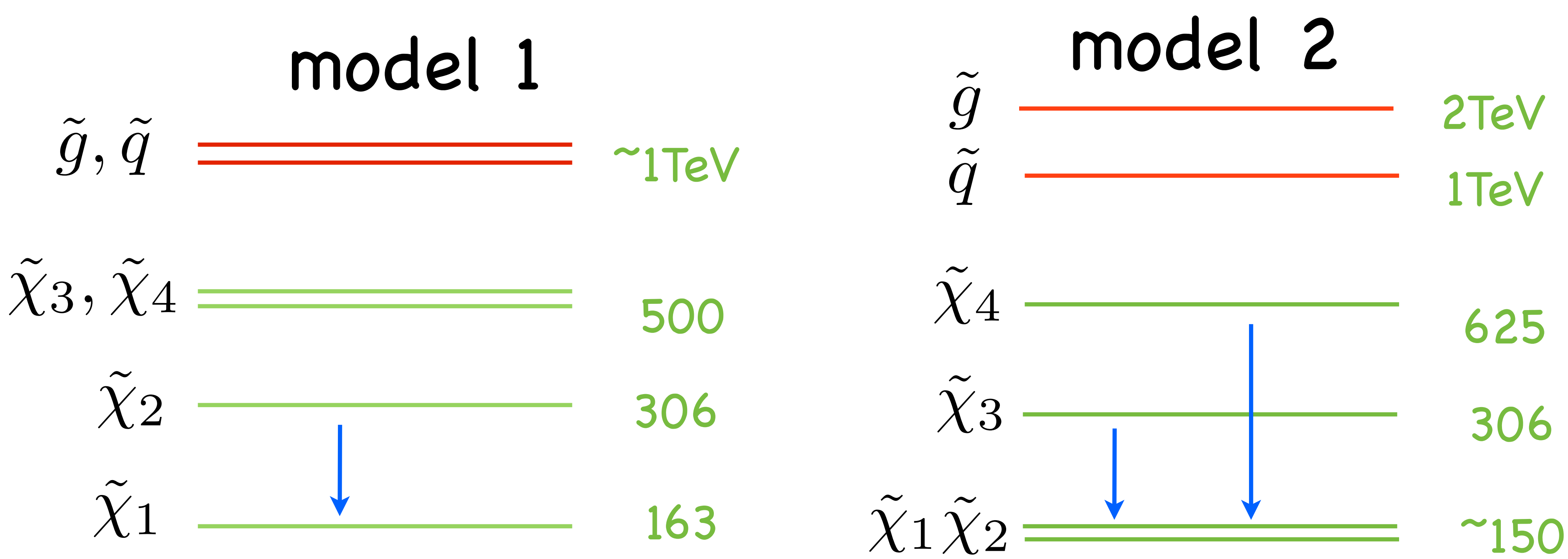
- Boosted Higgs is generic

Gori,Schwaller and Wagner(2011)

Gunion et al(1987); Baer,Bisset,Tata & Woodside(1992);
Denegri, Majerotto and Rurua, CMS-NOTE-1997-094;
S. Abdullin et al. (CMS Collaboration) (2002);
I. Hinchliffe et al. (ATLAS Collaboration) (1997);
Datta, Djouadi, Guchait and Moortgat (2004);
Kribs,Martin,Roy and Spannowsky(2009,2010)

Test our approach

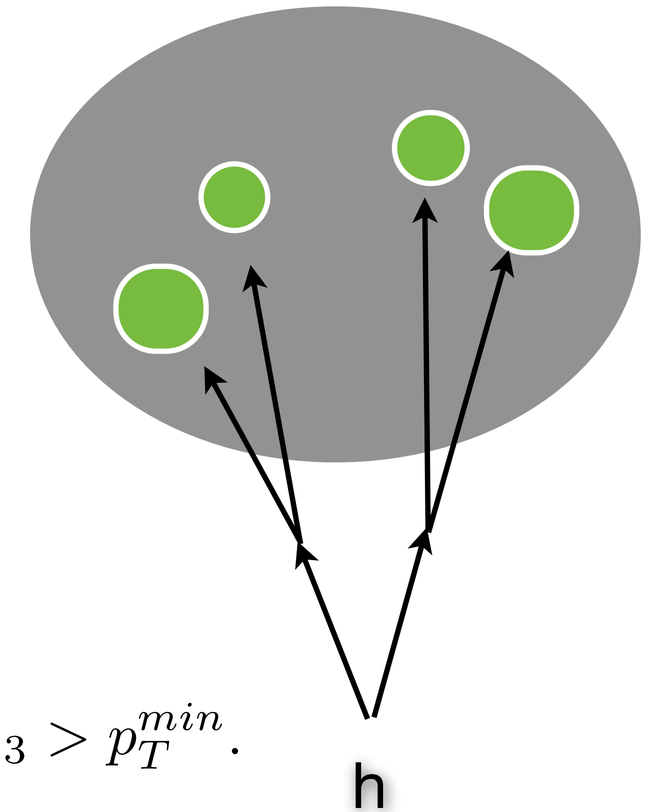
- Two MSSM spectra: large mu/ small mu
- Force h->2η->4j
- Higgs signal 0.8pb 0.1pb
- Pt>300GeV 40% 50%



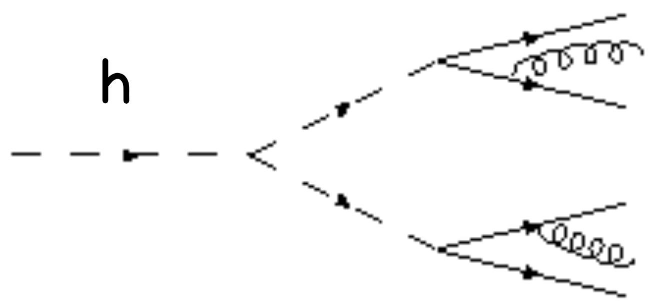
Analysis path

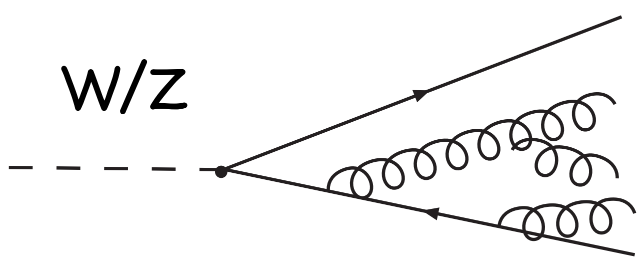
- Inclusive productions: gluinos/squarks -> cascade decay
    - Signals: h + jets + MET
    - Generic from cascade decays: multi-bosons(w/z/h) + jets + MET
- SUSY cuts: at least 3 jets, leading two jets P_T>(180,110)GeV, (H_T,MET) > (500,200)GeV
- Jet analysis --> identify Higgs jets (BDRS + additional cuts)
- Consider $m_\eta \in [5-30]$ GeV $m_h \in [90-120]$ GeV

Light η (~10GeV)



- η reconstructed automatically from the clustering
- Higgs jet selected and reconstructed from BDRS
- Additional kinematical cut -- η is scalar
  - cut on extra subjet $$\beta_{\text{flow}} \equiv \frac{p_{T,j3}}{p_{T,j1}+p_{T,j2}}, \quad \text{if} \quad p_{T,j3} > p_T^{min}.$$
  - cut on the subjet mass $$\alpha_{\text{MD}} \equiv \frac{\min(m_{j1}, m_{j2})}{\max(m_{j1}, m_{j2})}$$



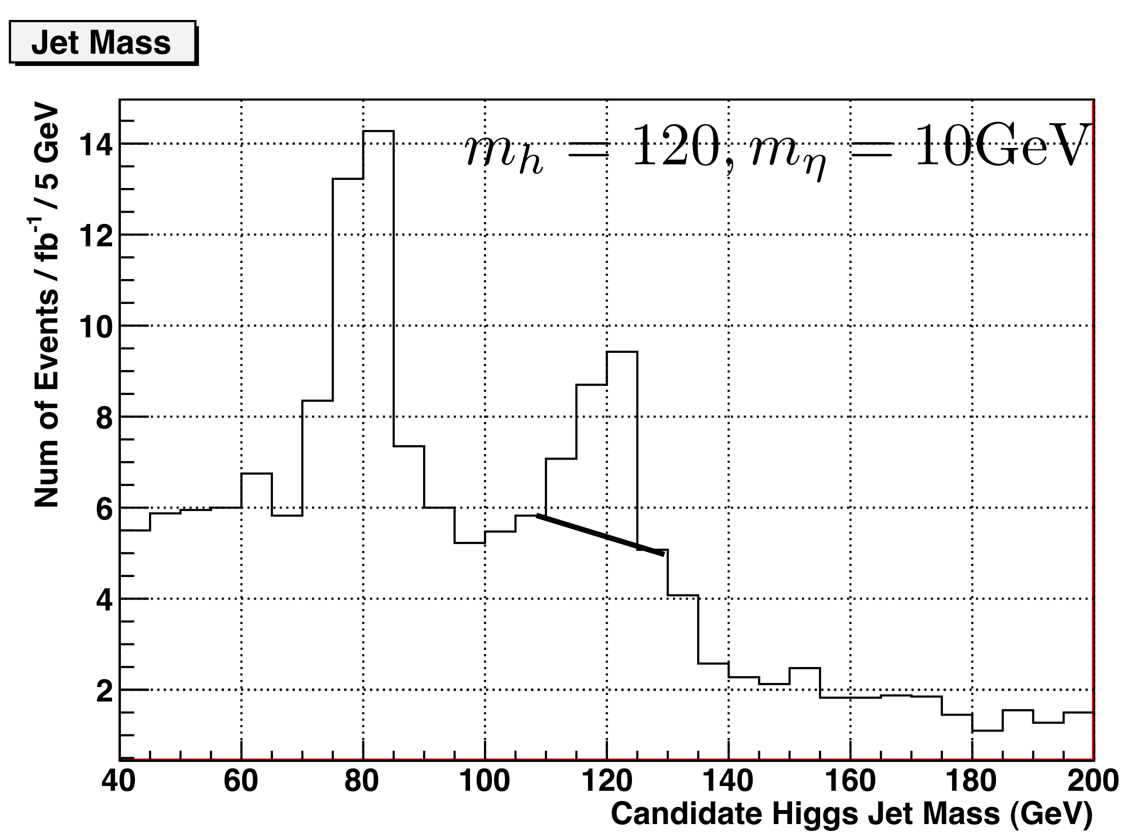


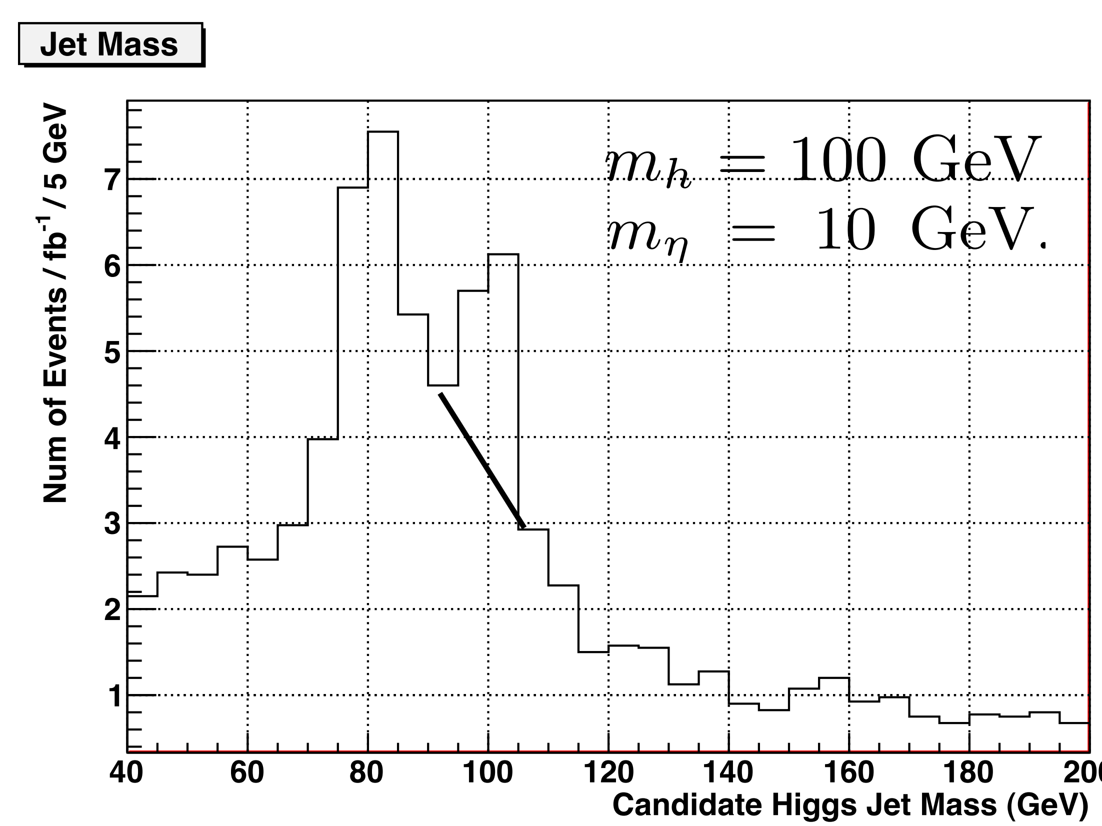
Result

- Jet mass distribution of all reconstructed jets --> Two resonances : W & Higgs
- BDRS + other kinematical cuts (cut 75% on W/Z, but 30% on Higgs)
- Estimate of discovery with 10/fb. Caveats: SUSY background model dependent

model 1

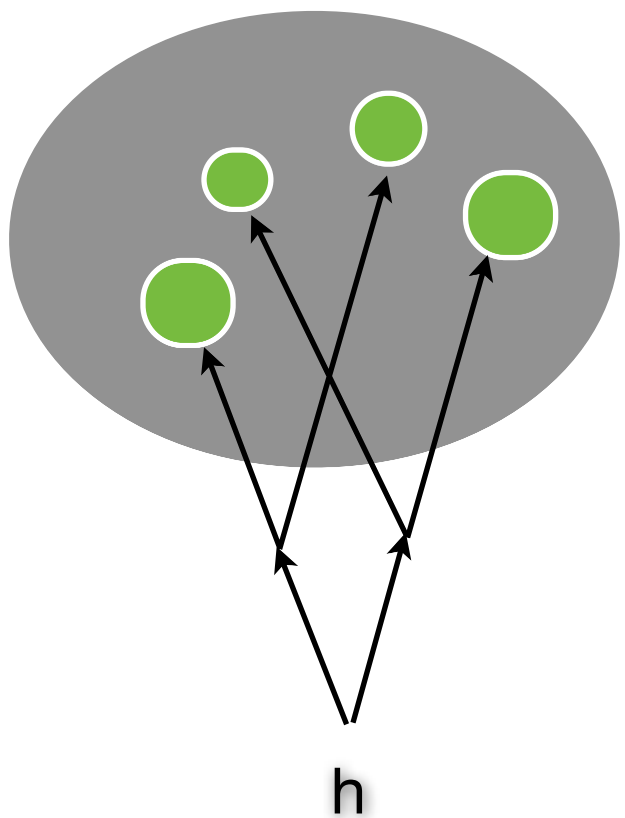
model 2 similar





Heavier η (~30GeV)

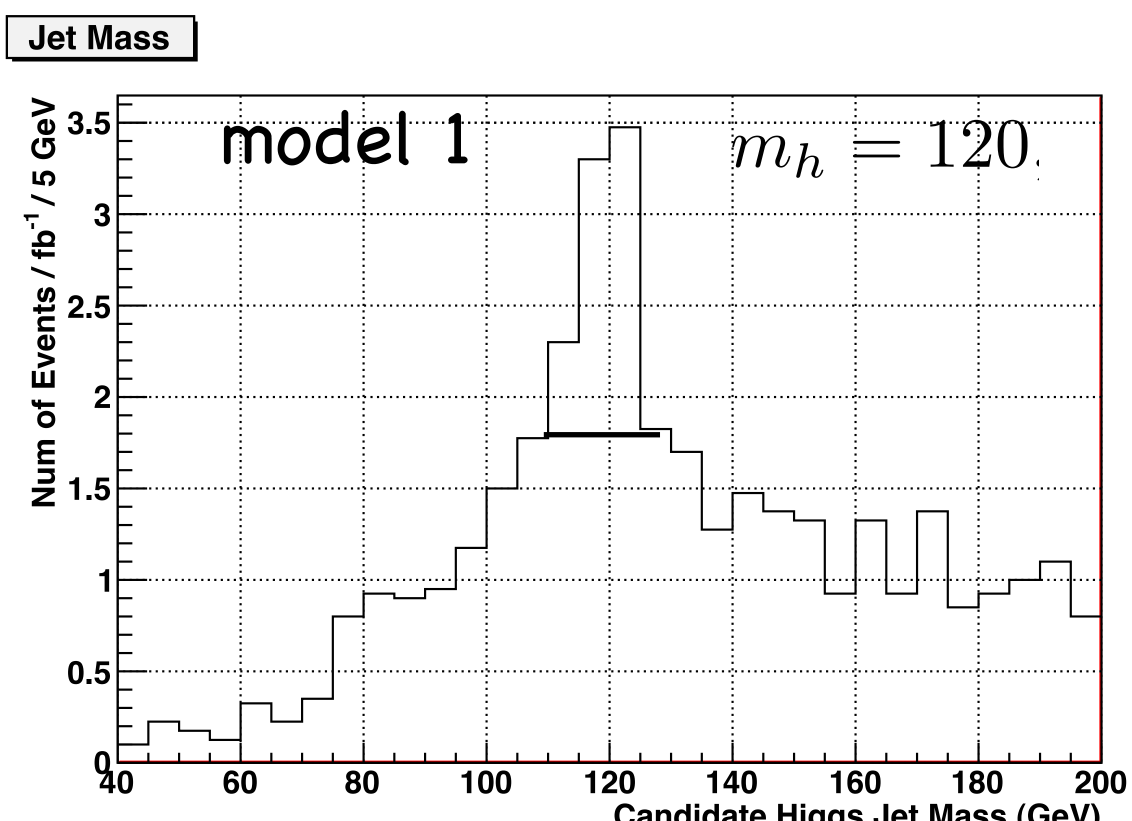
- Larger angle for the partons from η decay --> four final partons more equally distributed
- Four-prong final state is itself hard to mimic
- Require 3 or 4 subjets after reclustering --> enough to reduce QCD jets as well as W/Z jets
- We take R(subjet) =0.25, N(subjet)>3 with pt>15GeV

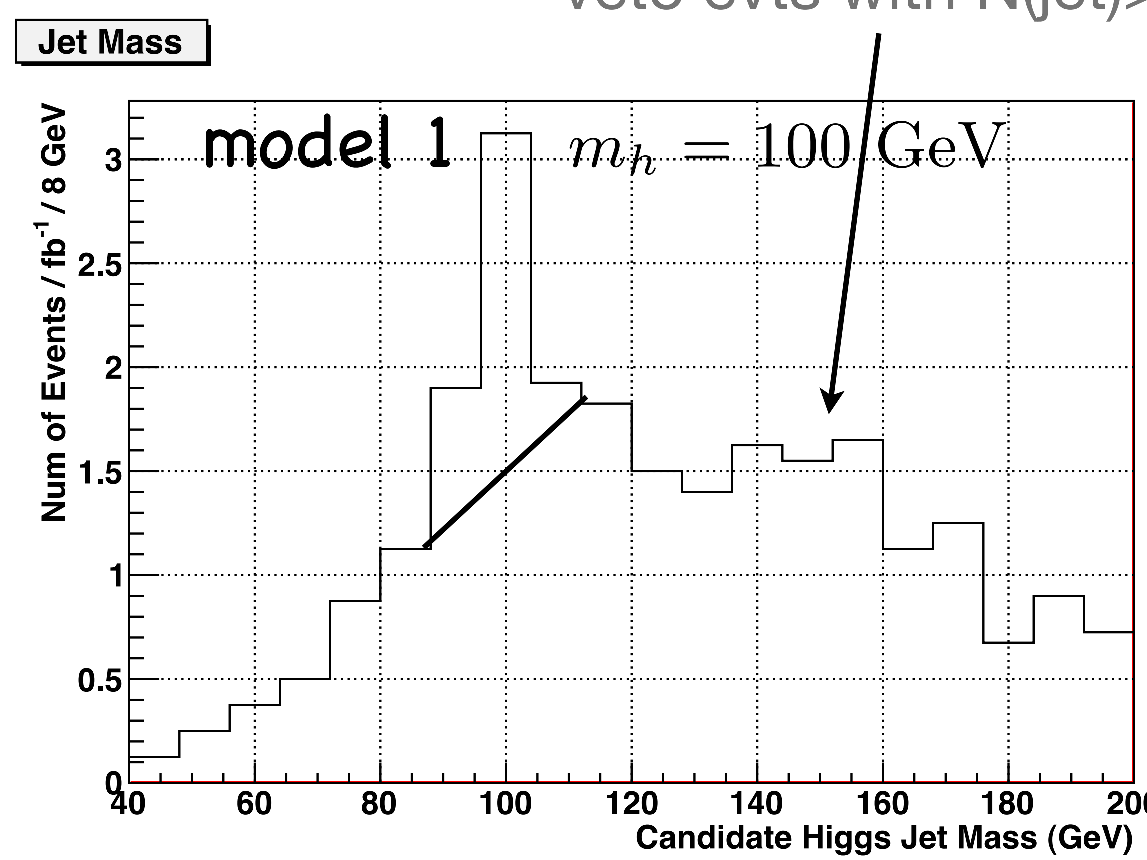


Result

- Clean resonance!
- Low mass candidates suppressed and no W/Z peaks
- Efficiency is lower and the more data is needed --> ~10-30/fb

combinatorics large,
veto evts with N(jet)>7





model 2 similar

Conclusions

- Search the light jet final states maybe the right way to find Higgs
- It's difficult in the conventional way and with SM productions
- Maybe the presence of BSM new particles are the cure
- A new resonance give a hint of Higgs, but confirm it require other channels
- Discovery the light pseudo-scalar also very important, measure the decay branching ratio of Higgs?
- More work needs to be done before Higgs is being discovered

Backup Slides

Model	1	2
$m_{\tilde{q}_{L,R}}$	$940, 910$	1000
$m_{\tilde{\ell}}$	1000	1000
$m_{\tilde{g}}$	949	2036
$m_{\chi_1^0}$	163	138
$m_{\chi_2^0}$	306	-158
$m_{\chi_3^0}$	-518	306
$m_{\chi_4^0}$	535	625
$m_{\chi_1^\pm}$	305	148
$m_{\chi_2^\pm}$	534	625
$\tan\beta$	10	10
μ	512	150

$\sigma(\tilde{g}, \tilde{q})$	2.5 pb	0.41 pb
$\mathrm{BR}(\tilde{q}_L \to h)$	30%	22%
$\mathrm{BR}(\tilde{q}_L \to Z)$	3%	25%
$\mathrm{BR}(\tilde{q}_L \to W)$	64%	48%
$\sigma \cdot \mathrm{BR}(h)$	0.29 pb	0.04 pb
$\sigma \cdot \mathrm{BR}(h + W/Z)$	0.47 pb	0.1 pb
$\sigma \cdot \mathrm{BR}(W/Z)$	1.04 pb	0.23 pb

Simulation details

- Event generation (Pythia 6.4) with ISR/FSR, MPI
- Normal jet -- use C/A with R=0.5 (fastjet)
- SUSY signal cut (similar to CMS)
    - N(jet)> 2 , pt(j1,j2)>180,110GeV
    - HT>500 GeV, MET > 200 GeV

m_h, m_η	$(120, 10)$	$(100, 10)$	$(120, 30)$	$(100, 30)$
R	1.2	1.2	1.0	0.9
μ	0.667	0.667	0.667	0.5
$\alpha_{\rm MD}$	> 0.7	> 0.8	> 0.4	> 0.4
$\beta_{\rm flow}$	$< 2\%$	$< 0.5\%$	-	-
$p_T^{\rm min}$	2.0	1.0	-	-
$R_{\rm sub}$	-	-	0.25	0.25
$n_{\rm subjet}$	-	-	≥ 4	≥ 4
$p_{T,\rm sub}^{\rm min}$	-	-	15	17